EXPERIMENTAL AEROMECHANICS

AFOSR GRANT # (or LABTASK #)

Roger L. Kimmel
Air Vehicles Directorate
Air Force Research Laboratory
Wright-Patterson AFB, OH

Abstract
Analysis of data obtained on the stability of the three-dimensional hypersonic boundary layer on an elliptic cone was concluded this year. The new focus of the task is acoustic receptivity of hypersonic boundary layers. Efforts this year have focused on introduction of acoustic noise in supersonic flows. This abstract presents initial experimental results on the introduction of acoustic disturbances into a supersonic freestream.

Introduction
Hypersonic flight improves weapon survivability and response time. Boundary layer transition to turbulence is important to hypersonic vehicle design primarily because turbulence increases heat transfer to the vehicle. Higher heat transfer generally requires higher-performance thermal protection, with increased weight and cost. Transition also impacts engine and aerodynamic performance. Increased drag from turbulent skin friction is important to hypersonic vehicles with large wetted areas and extended flight times. These factors place a premium on understanding transition for prediction and control.

Until the early 1990's, linear stability theory formed the basis for the most advanced tool for hypersonic boundary layer transition prediction, the "e^N" method.[1] The e^N method, however, is still fundamentally a correlation method. Recent advances such as Parabolized Stability Theory,[2] Direct Navier Stokes Simulation,[3] and Compressible Linear Navier Stokes,[4] open the possibility of computing finite-amplitude disturbance growth from receptivity through breakdown. Since the receptivity process is intrinsic to all transition processes, it was decided to study receptivity to provide new physical insight and data for computational benchmarking.

Objective
The objective of this effort is to investigate the physics of compressible boundary layer receptivity in order to validate theoretical and computational models and uncover new phenomena.

Approach
Two models, a wedge and a cone, will be constructed. The models will be constructed to run in either the Purdue Quiet Flow Ludweig Tube (PQFLT) or a NASA Langley quiet tunnel. Acoustic disturbances will be generated upstream and measured at the model station in the absence of the model. The interaction of the disturbances with the model

leading edge and boundary layer will then be measured to determine the receptivity coefficients. The experimental efforts will be closely coordinated with computational and theoretical efforts described in the section on technology transfer.

Progress

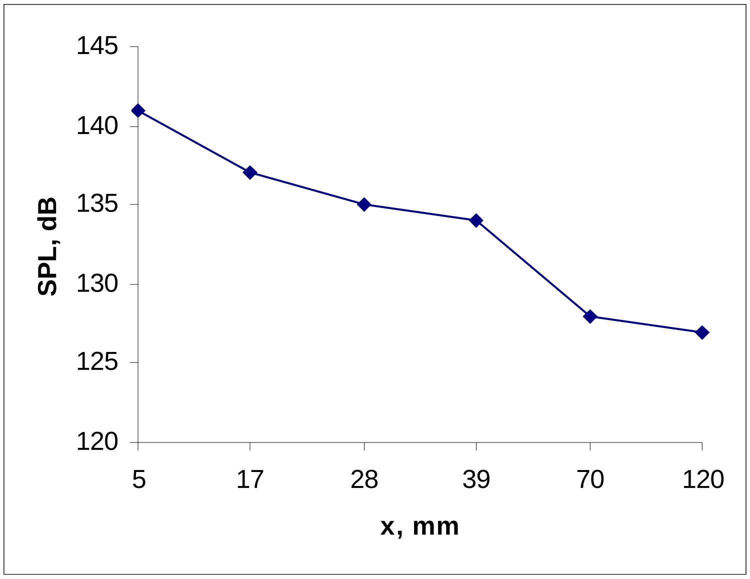
In subsonic receptivity experiments, acoustic disturbances have been generated using speakers. In Saric's experiments,[5] the speakers were located around the circumference of the plenum of the wind tunnel and were phased so as to generate planar acoustic waves normal to the freestream velocity. Several methods were considered for introducing acoustic disturbances in a supersonic wind tunnel settling chamber, based on older work. Sparks and double diaphragm shock tubes were investigated in the early 1960's as sources for dynamic blast-loading effects.[6,7] Several factors make introduction of acoustic waves in the settling chamber difficult. One issue is that only fast waves (those traveling at U + a) can pass the sonic throat. Also, sound levels are attenuated through the throat passage.[8] For these reasons, sound introduction in the test section was examined.

Ultrasonic transducers (UT) were explored as a means of generating acoustic noise. A fruitful search occurred in the proximity sensor community. These sensors generally operate below 1 MHz and are designed as air transducers. Piezo-ceramic transducers appear to offer the high amplitude output in a compact package. The APC 40 kHz transducer, 16 mm diameter, was bench-tested in the laboratory. The transducer was excited by a 40 kHz, 5 V peak-peak sine wave from a signal generator. The acoustic signal was sensed with an Entran pressure transducer mounted in the flat end of a cylindrical metal plug. The stated transducer sensitivity was 2.175 mV/psi, and output was amplified 1000x. The acoustic signal could be blocked by placing an obstruction between the transducers. When the face of the plug was normal to the (UT) face, the amplitude of the Entran showed distinct peaks every one-half wavelength from the UT.

The plug face was rotated approximately 45 deg. from normal to the UT face. This reduced the amplitude of the resonant peaks, although some remained. The Entran output was then recorded at several distances from the UT. The Entran peak-peak voltage output was converted to pressure using the stated transducer sensitivity and gain, divided by two to take into account the wave reflection at the plug face, and divided again by the square root of two to obtain rms pressure. This was referenced to 2×10^{-5} Pa to obtain dB units. Results are shown in Fig. 1.

In order to see how low a signal level was measurable, the ultrasonic transmitter transducer (UT) was placed in a vacuum tank. A 40 kHz ultrasonic receiver (UR) transducer was used to measure the UT output. A sample signal taken at 0.2 psi pressure produced a 30 mV output. The value of $\rho c / (\rho c)_{atm}$ for this case is 0.013. This compares to $\rho c / (\rho c)_{atm} = 0.009$ for the PQFLT. This shows that the UR might be used to measure signals at wind tunnel conditions. The UR responds only at its resonant frequency, 40 kHz, but in a receptivity experiment other frequencies would be filtered out anyway. The major drawback of these transducers is that the smallest size they come in is 10 mm OD.

Orifices will be tested on the bench to see if they improve spatial resolution, and how much they attenuate the signal. The vacuum chamber tests indicate that the UR's give a linear response with pressure, and thus might be calibrated to provide quantitative results.
Figure 1. Decibel sound pressure levels produced by APC 40 kHz transducer.



A harmonic point source in supersonic flow will generate a pattern of constructive and destructive interference due to the overlap of fast (U+a) and slow (U-a) wavefronts, making it difficult to separate them. Alexander Fedorov[9] has suggested impulsive excitation to avoid this problem. A spark source was set up in the laboratory to examine the acoustic structure of a typical spark. The source was a Xenon Corporation Model 437-B Nanopulse ™ System. Two schlieren photographs taken 50 and 100 microseconds after spark firing are shown in Fig. 2. The complex multiple wave structure is believed to be due to the spark gap geometry. The shock velocity decreases as the shock radius increases, which is typical of spherical shocks. A rough estimate of the shock Mach number for the 50 microsecond delay is obtained by dividing the measured shock radius by the time delay. This gives an average Mach number of approximately 1.3. The shock velocity for the second case is estimated by dividing the difference in the measured radii between the two cases by 50 microseconds. This gives an average Mach number of 1.2. The spark source is undergoing further investigation.

Results and Future Work

The piezoceramic transducers meet amplitude requirements in ambient air, but their amplitude at wind tunnel pressures may be too low. Spark sources clearly create a large-amplitude disturbance in still air, and may be useful as a source in the wind tunnel. Upcoming work will focus on assessing these sources in supersonic flow. These sources and techniques will then be used in preliminary receptivity measurements in the PQFLT.

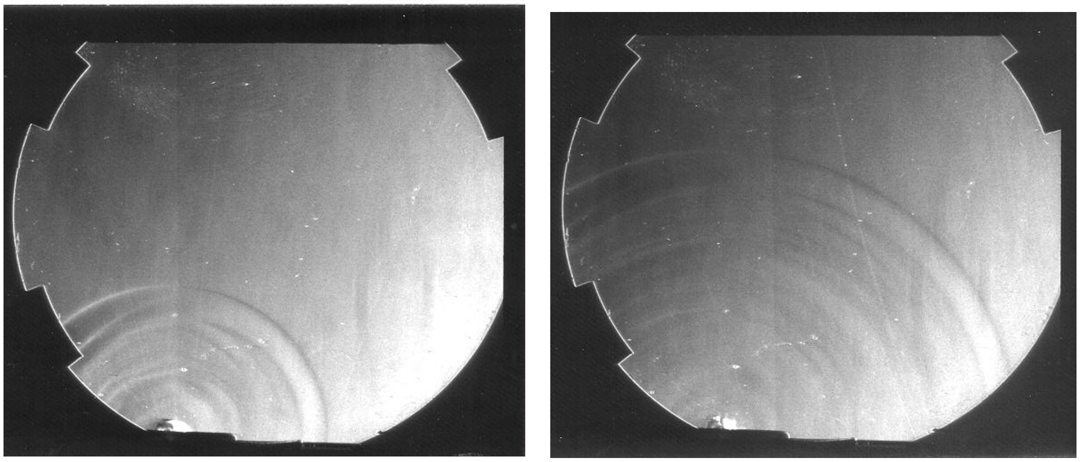


Fig. 2. Schlieren of spark-induced shock 50 μsec (left) and 100 μsec (right) after spark.

Personnel

The task manager is Roger Kimmel (Ph.D., Princeton University). John Schmisseur (Ph.D. Purdue University) and Jonathan Poggie (Ph.D., Princeton University) will staff the task. All are members of the Air Vehicles Directorate of the Air Force Research Laboratory. Dr. Gregory Buck (Ph.D. Arizona State University) has participated this summer under the AFOSR summer faculty program.

FY98 Publications

Poggie, J. and Smits, A. J., "Wavelet Analysis of Wall-Pressure Fluctuations in a Supersonic Blunt Fin Flow," *AIAA Journal*, vol. 35, no. 10, pp. 1597-1603, October 1997.

Kimmel, R. L., and Poggie, J., "Laminar-Turbulent Transition in a Mach 8 Elliptic Cone Flow, Part I: Overall Flow Features," submitted to *AIAA Journal*, June, 1998.

Poggie, J., and Kimmel, R. L., "Laminar-Turbulent Transition in a Mach 8 Elliptic Cone Flow, Part II: Traveling Instability Waves," submitted to *AIAA Journal*, June, 1998.

Ladoon, Dale W., Schneider, Steven P. and Schmisseur, John D., "Resonance in a Forward-Facing Cavity at Mach 4 Using Controlled Perturbations", Accepted for Publication in the *Journal of Spacecraft and Rockets*.

Schmisseur, J.D., Collicott, S.H. and Schneider, S.P., "Laser-Generated Localized Freestream Perturbations in Supersonic/Hypersonic Flows", AIAA Paper 98-2495, 20th AIAA Advanced Measurement and Ground Testing Technology Conference, Albuquerque, NM, June, 1998.

Schmisseur, J.D., Schneider, Steven P. and Collicott, Steven H., "Receptivity of the Mach-4 Boundary-Layer on an Elliptic cone to Laser-Generated Localized Freestream Perturbations", AIAA Paper 98-0532, AIAA 36th Aerospace Sciences Meeting, Reno NV, January 12-15, 1998.

Poggie, J., and Kimmel, R. L., "Traveling Instabilities in Elliptic Cone Boundary-Layer Transition at Mach 8," AIAA Paper 98-0435, 36th Aerospace Sciences Meeting, Reno, NV, January, 1998.

Kimmel, R. L., and Poggie, J. "Effect of Total Temperature on Boundary Layer Stability at Mach 6," to be presented, 37th AIAA Aerospace Sciences Meeting, Reno, NV, January, 1999.

Poggie, J., "Thermal Inhomogeneity and Exothermic Reactions in Weakly-Ionized Gas Flows," to be presented, 37th AIAA Aerospace Sciences Meeting, Reno, NV, January, 1999.

Schmisseur, John D., "Receptivity of the Boundary Layer on a Mach-4 Elliptic Cone to Laser-Generated Localized Freestream Perturbations", Ph.D. Dissertation, Dept. of Aeronautics and Astronautics, Purdue Univ., December 1997.

Kimmel, R. L., and Poggie, J., "Three-Dimensional Hypersonic Boundary Layer Stability and Transition," WL-TR-97-3111, 1998.

Honors and Awards

Dr. Poggie received a Best Presentation Award at the 1998 AIAA Dayton Symposium on Aerospace Science and Technology.

Technology Transition

This task is closely coordinated with experimental efforts by Steve Schneider at Purdue University. The goal of the task is to test in the Mach 6 quiet facility being developed by Schneider. We have been in close contact with him to discuss options for acoustic sources and sensors and to consult on the design of his facility.

Work is also closely coordinated with Alexander Fedorov of the Moscow Institute of Physics and Technology. Fedorov is under EOARD and AFOSR grant to develop receptivity theories for hypersonic boundary layers as a follow-on to a joint EOARD/AFOSR/WL FY97 task on acoustic receptivity of hypersonic boundary layers. We have worked closely with Fedorov in designing the experiment.

A Phase I SBIR was awarded by AFRL/VAAA to High Technology Corporation to develop an axisymmetric Compressible Linear Navier-Stokes code to study hypersonic boundary layer receptivity. The contract will be managed by Dr. Kimmel to ensure coordination between this 6.1 task and the SBIR. The High Technology principal investigator, Dr. Mujeeb Malik, has provided input into the design of the experiment. Additional, informal coordination has been carried out with Xiaolin Zhong, UCLA.

Acknowledgment / Disclaimer
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